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Foundations of Thermoelectronics

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Abstract
The construction of the foundations of thermoelectronics became possible only after the correction of thermodynamic errors in the traditional theory of semiconductor electronics. It was these errors that determined the saturation of the operating parameters of semiconductor electronic devices, in particular, the saturation of the maximum clock frequency of processors. But in semiconductors, although these thermodynamic errors manifested themselves not only in the instrumental, but also in the technological aspect, they did not prohibit semiconductor electronics themselves. It's just that in the theory of semiconductor devices there were a number of qualitative errors that practitioners compensated for with "empirical corrections. So an electronics engineer often made devices not according to a strict theory (which simply did not exist until now), but on a hunch and according to empirical local laws. What was aggravated by the fact that ALL physics was "stuck" on the use of flat electron orbitals, which Pauling introduced for "two-dimensional" graphite and for which he received the Nobel Prize. But, Pauling himself, as an honest scientist, having discovered his mistake, tried to correct it by introducing "curved" orbitals for graphite itself. Now, after the restoration of the Planck-Einstein Quantization, it is shown how to get the correct orbitals instead of the mystical Schrödinger wave functions [1, 2, 3].
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Introduction
The dimensional thermoelectric effect in silicon carbide crystals, which I initially discovered back in the 1980s, showed insufficient completeness of thermoelectric phenomenology to describe thermo-EMF and output resistance in microstructures with potential barriers (Fig. 1).

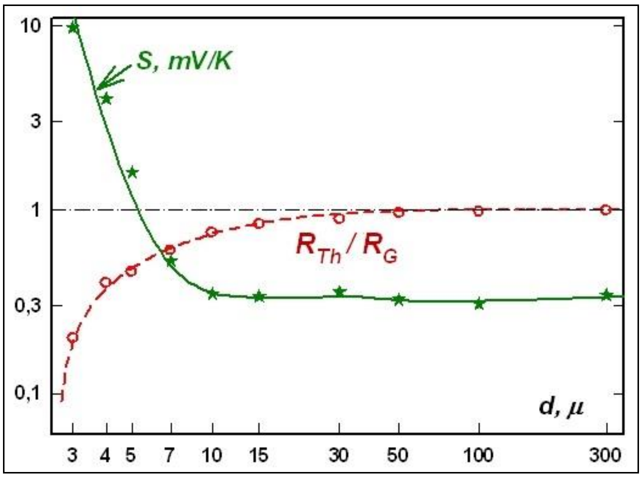

Fig 1: Dependences of thermo-EMF (originally it was believed that this is the diffuse Seebeck coefficient) and the ratio of the output thermoelectric resistance to the galvanic resistance of a SiC semiconductor crystal depending on its size (thickness along the heat flux)

But a rigorous theoretical extension of the purely diffuse (as analysis showed) theory of thermoelectricity was made by me later. And then, neither the laboratory of thermoelectricity of the Ioffe Institute, nor the international thermoelectric community dared to deviate from traditional thermoelectric concepts and with the need to correctly take into account the concentration force. Take it into account as it is done in the p-n junction theory. And the management of the Global Thermoelectric company, which arranged a radio conference with me at the beginning of this century, summarized both our discussion and the general position of the thermoelectric community by saying: “We are now the world's largest manufacturer of thermoelectric generators using well-established traditional technology. And where will we be if we switch to the Intel technology you propose for thermoelectricity”.

But even then, albeit at a qualitative level, I already felt that there is a “reverse side of the coin”, that phenomenology and as a result, calculations of the characteristics of the p-n junction are also not complete without taking into account the temperature force traditionally used in thermoelectricity. I understood, showed at a qualitative level to the management of Intel that it was precisely because of taking into account the temperature force that they reached the saturation of the processor clock frequency with an increasing miniaturization of individual elements (an increase in the number of elements in a chip). But Intel, for its part, was afraid to move away from the traditional technology for manufacturing processors, and tried not to solve the problem correctly, but to get around it due to multi-core. But this method of increasing the number of elements, even then it was obvious, would not allow going beyond the logarithmic dependence of the speed of processors on the number of elements in them. Now my early qualitative calculations have received rigorous confirmation in the expansion of electronics to thermoelectronics.

Historical errors of semiconductor electronics and their correction

The historical consideration of electronics without taking into account heat flows has imposed a number of restrictions on the design of devices and devices based on it. In addition, they led to a number of "theoretical" bans on the existence and the possibility of registration, which was revealed in the study of the previously described Local thermo-EMF. At the same time, before turning specifically to polymers, it is necessary to make a significant clarification. Lack of understanding of the physics of Local thermodynamic effects not only imposed a ban on the Local Effects themselves, but also led to a false attribution (even. WIKIPEDIA) of the device to a photo-thermoelectric converter, while it contains a simple photo-conversion of the thermal radiation flux.

This happens in Science, unfortunately, not infrequently. The ideas of its Creators are not fully understood, but picked up by the developers, they are actively moving forward, but with distortions and errors. So, now that the fundamental sections of Physics have reached the modern level, it became clear that an entire industry has been formed-electronics, the instrumental and technological problems of which are related to the fact that the theory of p-n junction is built in violation of the laws of non-equilibrium thermodynamics and that this is largely determined by distortion Ideas that the Founders of electronics came up with purely intuitively.

So, it is in the p-n junction, first discovered in silicon carbide and described in the 30s of the last century by Oleg Losev, who himself immediately intuitively realized that this was a current device. And he was able to use it almost immediately: he created on it an LED, a photodiode, and a resistance transformer, which the Nobel laureates called in short (in English) a transistor. But the physics of the p-n junction and the description of the operation of the listed devices based on the p-n junction were built by analogy with a radio tube, which, in principle, is a field device. Thus, when solving various problems for semiconductor devices in the p-n junction, the cause-current and the effect-voltage were rearranged. And the prominent physicist Abram Fedorovich Ioffe did not fully understand Losev then, who was half a century ahead of modern electronics. But Academician Ioffe, not like the current "luminaries of science", succeeded in conferring on him a candidate of physics and mathematics. sciences without defending a dissertation. And only after almost 100 years, the return to Losev's current circuit made it possible to significantly improve the characteristics of semiconductor devices.

Tauc is another, Czech Corypheus, ahead of his time. He was the first, immediately after the liberation of Prague by the Soviet troops, to establish the production of point transistors in Prague (formerly of the Bell company). And he immediately discovered thermoelectric effects in the p-n junction and honestly described them. But thermoelectricity itself was then (and still is) stuck at the macroscopic level and relegated Tauc's results to the category of anomalies.

The thermodynamic discovery by Ilya Prigogine of the production of local entropy helped to restore the correct description of the physics of the p-n junction, which made it possible to understand that in the p-n junction, described for the reasons noted above, within the framework of a truncated concentration-electric phenomenology, it is necessary to use an extended phenomenology supplemented by a heat flow [1-23]. The standard band structure of the transition itself (Fig. 2a) is modified when the temperature force is taken into account.

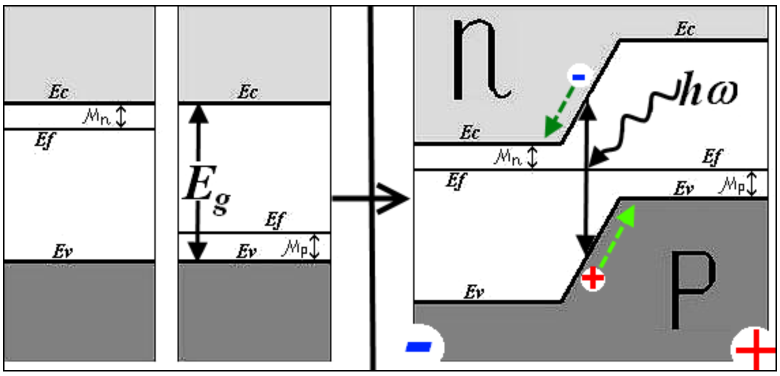

Fig 2a: The traditional scheme for the transformation of energy bands of semiconductors with different types of conductivity upon their contact and the opening of the p-n junction formed in this case when the i-region is irradiated with light

At the same time, the energy diagram of the equilibrium p-n junction is somewhat modified, which, without taking into account the temperature force, gave, as shown in Fig. 1, the potential barrier value approximately equal to the band gap of the semiconductor. Taking into account the temperature force, in the absence of a heat flux, the value of the potential barrier turns out to be equal to half the band gap (Fig. 2b). And when it turns on the heat flow, the value of the potential barrier will increase until a tunnel breakdown occurs (Fig. 2).

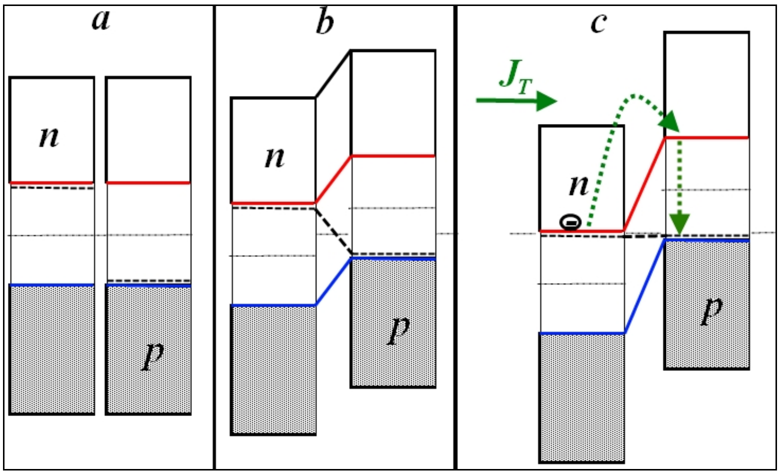

Fig 2b: Energy diagrams of two semiconductors of different types of conductivity: a-before bringing them into contact, b-equilibrium state after their contact at equal temperatures, c-equilibrium state with heat flow through the p-n junction

As shown in Fig. 2b, between semiconductors brought into contact in an equilibrium state due to the balance of electric and concentration forces, the difference in electric potentials at the contact (red line is the bottom of the conduction band, blue line is the top of the valence band) is equal in magnitude and opposite in sign to the difference at the boundary of the concentration potential (dashed black line). Thus, given in Fig. 1b, in accordance with the complete system of equations for thermodynamic forces and flows, it already allows eliminating the theoretical equal to 2 in the description of the transition without a temperature gradient, which was associated with an empirical coefficient due to the imperfection of materials. The potential difference across the transition plates is equal in this case to half the band gap. And the equality of concentration potentials corresponds to the Local Thermo-EMF and occurs, of course, only with a heat flow through the transition (Fig. 2c). In this case, the current-voltage characteristic (CVC) of the p-n junction, of course, depends on the temperature difference on its plates (Fig. 3). And on the I-V characteristic of the upper left quadrant, a region of positive currents arises at negative voltages at the p-n junction, which, in full accordance with the concepts of generators (the simplest-an electric battery), is the region of electric energy generation due to the flow of heat flowing through the junction.

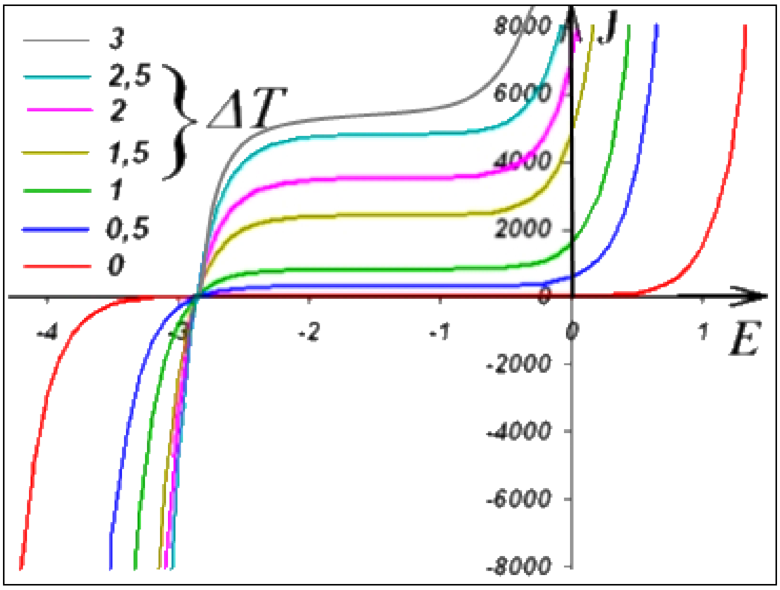

Fig 3: Generator characteristic of a p-n junction, showing its tunneling self-breakdown

The oscillator characteristic of the transition is constructed without taking full account of the specifics of the equilibrium state, taking into account the local production of Prigogine's entropy. In this case, zero current through the junction corresponds to a zero-temperature drop. But in fact, the p-n junction is Maxwell's demon-a "gear" wheel separating hot and cold current carriers, in principle, allowed at the micro level by the production of Prigogine's Local Entropy. And the mechanism of its operation is obvious from Fig. 2: when semiconductors come into contact, its asymmetry (polarity) occurs. At the same time, to start the electron transfer process, an energy equal to half the band gap is sufficient, while after their transfer and annihilation with holes, their reverse transfer requires an energy equal to the full band gap. So, a local temperature drop occurs on the plates of the p-n junction, which determines the local thermodynamic equilibrium. In this case, the experiment shows that the CVC has a shape fundamentally similar to that shown in Fig. 3.

The use of extended concentration-electrical-thermal phenomenology made it possible to correctly take into account Losev's current p-n junction, and to transfer the "anomalous" thermoelectric power discovered by Tauc in the p-n junction to the category of normal-local, and to describe new experimental results of studies of contact thermoelectric power. In addition, the extended phenomenology made it possible to understand that macroscopic thermoelectricity is artificially limited only by diffuse thermoelectric materials and showed that for diffuse thermoelectrics, the efficiency of thermoelectric conversion achieved in practice is already close to the theoretical limit.

In addition, extended phenomenology has shown that the efficiency of thermoelectric conversion based on local thermoelectric power has no diffuse limit and can be dramatically increased by several times compared to that achieved using the Seebeck effect in traditional diffuse materials (Fig. 4).

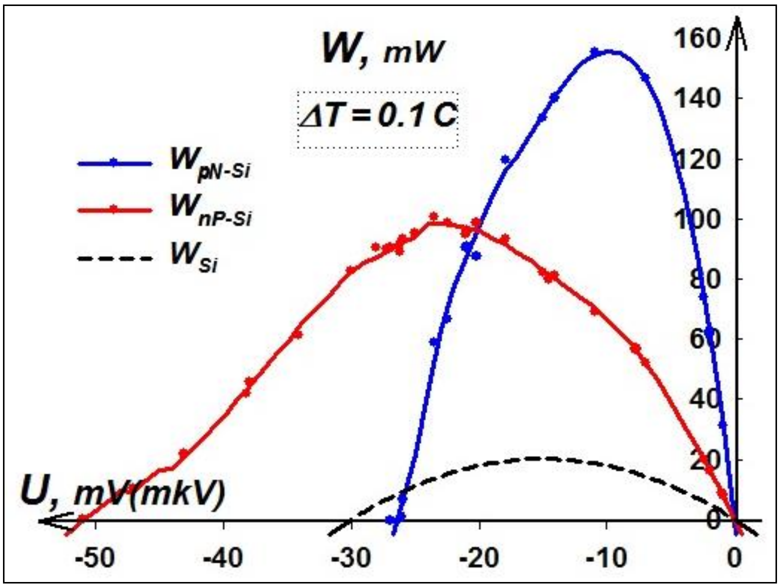

Fig 4: Thermo-generator characteristics of p-n junctions and optimally doped silicon (for silicon, the optimal EMF-μV is three orders of magnitude lower than that of p-n junctions-mV)

This was experimentally confirmed on the developed detectors based on Local Thermo-EMF in silicon junctions, the volt-watt sensitivity of which was obtained three orders of magnitude higher than that of detectors based on the traditional macroscopic Seebeck effect.

At the same time, the extended phenomenology shows that there can be complex, three-phase effects in the p-n junction, which makes it possible to optimize, in particular, the combination of local thermoelectric effects with photoelectric effects in it.

Conclusion

The study of Local Effects raised a number of fundamental questions that ended up in a fork: from-this cannot be, to this-elementary. This also applies to the registration of detected and previously referred to as anomalous Local thermo-EMFs, but not only.

But by and large, it is the ELEMENTARY Solution, in contrast to the Primitive, that allows you to create devices with fundamentally (dramatically) improved characteristics. This was the case before, when new devices were created based on the well-known First Principles, the same was confirmed when creating detectors based on the discovered NANO-effects, the study of which resulted in the previously missed NANO-Physics.

Thus, in order to achieve this cardinal improvement in the characteristics of devices and devices, it was necessary to solve a number of fundamental issues and a number of methodological measurement issues, and a number of issues related to the technology of manufacturing efficient semiconductor nanostructures, and a number of design issues.

Within the framework of this study, answers were obtained to a number of fundamental questions

1. Measurability of Local Effects.
2. The primacy in the effects of the current as the cause of the effect and the secondary nature of the voltage, as a consequence, taking into account external conditions.
3. Electric currents over potential barriers in semiconductors.
4. Thermal force in the p-n junction.

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